SATELLITE MEASUREMENTS OF THE METEOROID ENVIRONMENT

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ABSTRACT

A review of the most recent satellite measurements of the meteoroid environment by the Explorer XVI is presented.

The Explorer XVI was instrumented to measure the flux and hypervelocity interactions of meteoroids on satellite vehicles. A brief description of the satellite is presented and detailed information of several experiments for meteoroid detection is given.

Time histories of the penetrations encountered during the satellite's seven-month lifetime are given and penetration rates based on the effective time-area exposure to meteoroid influx are derived.

Forty-one penetrations were recorded in 25-micron thick beryllium copper while eleven penetrations were recorded in 51-micron copper. In addition six penetrations were recorded in 25-micron stainless steel and one penetration recorded in 76-micron stainless steel. Also there was recorded one penatration each in 51-micron and 76-micron copper. It is shown that these direct

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measurements indicate that the penetration characteristics of meteoroids in thin metallic materials are two-three orders of magnitude less than some previous estimates.

Data from the experiments are presented, analyzed, and compared with currently used theories, observations, and laboratory impact studies. An estimate of the flux of meteoroids capable of penetrating thin metallic sheets is made and this estimate is compared with other satellite flux measurements. It is shown that there is a great discrepancy between these measurements.

Details are given on a large satellite to be flown to determine the effect of meteoritic encounters on materials whose thicknesses approach nominal vehicle wall thicknesses. Author

2. Introduction

One of the hazards in the space environment is the possible encounter with extraterrestrial debris known generally as meteoroids. By virtue of the extremely high velocity of meteoroids, it is clear that a meteoroid impact with a space vehicle could be a catastrophic event. Consequently, the effects of these meteoritic encounters on space vehicles are a matter of concern in the design of spacecraft for various space missions.

The hazard from meteoroid impact can be properly evaluated with sufficient knowledge of the distribution of interplanetary matter in the solar system and the characteristics of crater formation in and penetration of spacecraft structures by such impacts.

A number of papers have been written on the subject of penetration of spacecraft by meteoroids.[1-5] Knowledge of the distribution of interplanetary matter in the solar system has been obtained from visual, optical, and radio-measurements of meteors, from accretion measurements in the earth's atmosphere and on the earth's surface, and from direct measurements using rocket probes and satellites, while information concerning the characteristics of impact cratering and penetration from meteoroid impacts have been obtained from laboratory hypervelocity impact studies and theory. Due to the indirect nature of such assessments these papers give only an estimate of the hazard. A more accurate appraisal of meteoroid hazard may be determined experimentally by exposing structural skin specimens to the meteoritic environment and by making direct measurements of penetration rates. This method for determining the meteoroid hazard was the objective of the Explorer XVI satellite.

The initial results obtained from the Explorer XVI (1962 BETA CHI I) satellite is presented below. From a comparison of the penetration rates with predicted estimates and meteoritic encounter frequency the meteoroid hazard in thin spacecraft materials may be appraised.

To accurately appraise the hazard in thicker materials, additional measurements must be made. A description of a large satellite to make such measurements is also presented below.

3. Description of Spacecraft and Experiments

Figure 1 is a photograph of the Explorer XVI satellite. The satellite was cylindrical in shape, approximately 72 inches long and 23 inches in diameter. It was built around the last-stage rocket motor of the launch vehicle, the spent case of which remained as part of the orbiting spacecraft. The weight of the Explorer XVI including burned-out rocket motor was 222 pounds.

This spacecraft incorporated five different experiments to obtain information on meteoroids. Figure 2 is a schematic of

The Explorer XVI satellite showing the location of the experiments. These experiments include impact detectors (piezoelectric transducers) and cadmium sulfide cells mounted on the forward part of the spacecraft; pressurized cells and additional impact detectors located on the base plate of some of the pressurized cells which are mounted on the center section of the spacecraft; and stainless steel covered-grid detectors and copper-wire detectors mounted on the aft part of the spacecraft.

The pressurized cell experiment, developed at the NASA Langley Research Center, Hampton, Virginia, was the primary experiment on the spacecraft. The author and Charles A. Gurtler of Langley are the experimenters.

Figure 3 is a drawing of the pressurized-cell detector. A total of 160 of the annealed beryllium-copper cells were mounted around the periphery of the rocket motor case in 5 rows of 32 cells each. Each cell was filled with helium. When the cell is punctured, the gas leaks out and the pressure loss actuates a switch that signals the telemeter of the puncture. Thus, after one puncture, the cell cannot indicate additional punctures.

A second experiment is the stainless steel covered grid detector developed by the NASA Lewis Research Center, Cleveland, Ohio. Elmer H. Davison of Lewis is the experimenter. Figure 4 is a sketch of this detector. The detectors, made from type 304 stainless steel segments, were mounted around the base of the fourth-stage motor and bonded to the outside of a thin continuous grid circuit. A puncture of the stainless steel cover will break the circuit beneath it, producing a change in electrical resistance.

A third experiment was developed by the NASA Goddard Space Flight Center, Greenbelt, Maryland, by Luc Secretan. A sketch of this experiment is shown in figure 5. Forty-six of these copper-wire cards are mounted on a cylindrical structure aft of the steel-covered grids. Each card consists of a continuous winding of 0.002- or 0.003-inch copper-wire closely wound on a melamine card. Each 0.002-inch card forms a separate detector, but the 0.003-inch detectors are formed from two cards in series. Detector operation is similar to that of the steel-covered grids in that a puncture, or break, of the wire causes a change in circuit resistance. These detectors, as well as the two types of puncture detectors previously described, cannot provide additional data once a puncture has occurred.

A fourth experiment used on this satellite is also illustrated in figure 5. This is the cadmium sulfide cell developed by the NASA Goddard Space Flight Center. Luc Secretan is again the experimenter.

The experiment consists of a light-sensitive cadmium sulfide element mounted beneath a sheet of 0.0025-inch plastic film (Mylar) with vapor-deposited aluminum on both sides. The purpose of the experiment is to determine the size of the hole left in the plastic (Mylar) by the penetrating particle, by measuring the change in electrical resistance caused by the sunlight admitted through the hole. Two of these cells were mounted on the nose section of the satellite.

Piezoelectric crystal transducers for detection of impacts and having three levels of mementum sensitivity were developed by the NASA Langley Research Center. Alfred G. Beswich is the experimenter. Twenty of the 0.005-inch thick pressurized cells were instrumented with transducers having the intermediate sensitivity level. A sketch of the transducer located beneath the base plate of the cell is shown in Figure 6. Two acoustically islocated "sounding boards" on the forward section of the spacecraft, also shown in Figure 6, were used for the remaining two levels of sensitivity.

4. Rate of Meteoroid Penetrations

Explorer XVI has performed as designed and has provided significant data on the penetrating capability of meteoroids in thin structural materials. In addition, data have been obtained on the frequency of impact by meteoritic particles. These data will be reported elsewhere when analysis is complete.

Figure 7 shows the accumulated punctures as a function of time for the penetration-type detectors. The data presented extend over the time period from December 16, 1962 (launch) through July 25, 1963. During 7½ months in orbit, forty-four 0.001-inch beryllium-copper and eleven 0.002-inch beryllium-copper penetrations have been recorded. There have also been six 0.001-inch stainless steel penetrations recorded in this time period as well as several penetrations of the vapor deposited 0.00025-inch Mylar film of the cadmium-sulfide experiment. As of April 18, 1963, one cadmium-sulfide cell was completely saturated with sunlight and was no longer useful as a meteoroid detector. These results will be reported elsewhere at a later date. Further there have been recorded one penetration in a 0.003-inch stainless steel skin and one penetration in each of the 0.002-inch and 0.003-inch copper wire.

There were no penetratinns recorded in either of the 0.005-inch beryllium copper or the 0.006-inch stainless steel.

The penetration rates were computed using the information shown in Figure 7. That is, the rates were computed for the total number of penetrations received through July 25, 1963, taking into account the decrease in exposed area following each penetration.

Tests have been conducted at the NASA Langley Research Center to ascertain a correlation of penetration depth in beryllium-copper with that in one of the more common structural materials such as aluminum. The results of these tests are shown in Figure 8. Aluminum projectiles 1/16-inch in diameter were fired into quasi-infinite thick aluminum and beryllium-copper targets at velocities up to about 17,000 ft/sec and respective depths of penetration determined. From these data it appears that the penetration depth in aluminum is about twice the depth in beryllium-copper for the same particles and velocities. Calmulations were performed to correlate the penetratéon depth in beryllium-copper with that in stainless steel. Results of these calculations indicated that the penetration depth in both materials is approximately the same.

Using these results and correcting for the shielding effect of the earth, the penetration rates are plotted at the corresponding thickness of aluminum and compared with two estimates of the penetration hazard in Figure 9. The error bars on the points are the 95% confidence limits. Although no penetrations were received in the 0.005-inch beryllium-copper, an upper limit on the penetration rate may be established. This upper limit is shown in the center of Figure 9.

The upper curve of predicted penetrations has been determined from the estimate of the distribution of interplanetary matter by

Whipple (1957)[3] and the experimental penetration criteria of Charters and Summers (1958)[6]. The lower curve has been determined from the estimate of the distribution of interplanetary matter by Watson (1941)[7] and the theoretical penetration of Bjork (1961)[4]. These two estimates were chosen since they represent what have been believed to be reasonable limits on the expected penetration rates. It is seen that there is a difference of over three orders of magnitude between the curves. These differences have been explained by Dubin[8] and will not be discussed here.

It is clear from the penetration rates established by the Explorer XVI data in the region where these data are statistically significant, that the Whipple (1957)[3] distribution combined with the Charters' and Summers' (1958)[6] penetration criteria greatly over-estimates the meteoroid hazard, while the Watson (1941)[7] - Bjork (1961)[4] estimate falls slightly below the actual measured data.

The figure represents our current state of knowledge on the meteoroid hazard environment. To accurately appraise the hazard in thicker materials, additional measurements must be made.

5. Discussion of Penetration Rates

Before discussing a planned experiment to determine the frequency of penetrations in materials whose thickness approach nominal vehicle wall thicknesses, it is of interest to compare satellite measurements of meteoritic encounter frequency with the penetration rates obtained from the Explorer XVI data.

Presented in Figure 10 are cumulative meteoroid impact rates as a function of mass as determined from several ground observations as well as direct measurements by probes and satellites. Shown are the Whipple (1957)[3], Watson (1941)[7], as well as the Whipple (1963)[9] estimate based on optical measurements of meteors. Also shown is the Watson (1941) estimate revised by Whipple in 1963. The curves labeled v.d. Hulst (1947)[10] and Ingham (1961)[11] are based on Zodiacal light measurements. Direct measurements are shown by the curves labeled McCracken et al,[12] and Soberman and Hemimway.[13] The Explorer XVI data points were determined from the previously presented data through the use of the Bjork penetration criteria. All data presented in this figure assume a mean meteoroid density of 0.44 gms/cm^3 and a mean velocity of 30 km/sec which is consistent with the analysis by Whipple (1963) based on optical meteor observations. The data point labeled Hawkins (1963)[14] is a preliminary result obtained by the Harvard Radio Meteor Project conducted by the Harvard College Observatory in which Dr. G.S. Hawkins is the principal investigator. This project is being supported by the NASA.

There is a great discrepancy (over four orders of magnitude) between the Explorer XVI data and the data of McCracken et al.

These direct measurements were made near the earth and their comparison indicate that although the earth may be encompassed by a relatively high spacial density of meteoroids, only a small percentage of these meteoritic particles are able to penetrate thin metallic surfaces. The data indicate further that the majority of meteoroids in the near-earth environment are probably not high density compact objects but may be of relatively low density. Further research is required in order to substantiate this.

However, if this is the case, it may only be necessary to desigh spacecraft for protection against penetrations from a very small fraction of the meteoritic matter about the earth. On this basis, the weight of material required for protection is considerably smaller than that required based on previous estimates of the penetrating capabilities of meteoroids in the neighborhood of the earth. On the other hand, it would be necessary to consider the complete content of meteoritic material in the design of optical surfaces and thermal coatings.

6. Description os Saturn-Launched Meteoroid Experiment

As mentioned previously, there is required additional measurements in order to appraise the meteoroid hazard in relatively thick materials. NASA has now under development an experiment to provide this appraisal. This experiment to be launched by a Saturn I - Block II launch vehicle will have an area 100 times greater than the Explorer XVI satellite and will be incorporated on a spacecraft referred to as the Micrometeoroid Measurement Satellite. By virtue of this large area, it will be possible to establish the penetration rates in material thicknesses up to about 0.016-inches. Shown in Figure 11 is an artist's sketch giving some of the pertinent details of the experiment. In the lower right the experiment is shown in the stowed-condition mounted on the S-IV stage of the launch vehicle. The deployment sequence is shown by the series of four sketches in the center of the figure. The uppermost sketch shows the experiment housed in the Apollo service module. In the next sketch, the Apollo command and service modules have been jettisoned. As may be seen, the experiment consists of a series of panels that open in a scissors-like fashion. The bottom sketch shows the spacecraft in the extended condition as it will be after injection into a near-earth orbit. In the fully extended condition, the experiment is about 96-feet long (about the size of the wingspan of a DC-6 airplane). The weight of the experiment exclusive of the attached burned-out S-IV stage is about 4,000 pounds.

A new meteoroid detector of the capacitor-type will be incorporated to record meteoroid penetrations. This detector has the attractive feature of being reusable after penetration.

A cross-section of a detector panel is shown in the middle left of the figure. A capacitor detector consisting of the aluminum material to be penetrated followed by a mylar dielectric bonded to a vapor deposited aluminum thin surface. Capacitor detectors are placed on both sides of the panel and separated by a foam core. The function of the core is to prevent a meteoroid penetrating one capacitor from penetrating another on the opposite side of the panel. Each capacitor detector is about 20" x 40" and several are placed on each panel. The reason for this is that should anyone short out, the complete panel will not become ineffective to record meteoroid penetrations.

The spacecraft will be placed in a near-earth orbit and will tumble in a random-like manner. When a penetration is received, the attitude of the vehicle will be recorded as well as the time of the event. In this manner, the direction of the impacting meteoroid may be determined, and it should be possible to determine the distribution of penetrating meteoroids in the near-earth environment.

This briefly describes the experiment. It can be seen that in addition to penetration rates in relatively thick materials, additional information on the meteoritic content in the near-earth environment should be obtained.

6. Conclusions

An attempt has been made to review the meteoroid hazard environment based primarily on the data obtained from the Explorer XVI. Although the Explorer XVI provided the first known penetrations by meteoroids in thin metallic skins, additional measurements must be made to appraise the hazard in thicker materials. An experiment soon to be placed into orbit to provide this appraisal has been described.

From a comparison of meteoritic encounter frequency and the penetrations recorded by the Explorer XVI there is an indication that the majority of meteoroids in the near-earth environment are not high density compact objects, but may be of relatively low density. Further research is required to substantiate this broad conclusion.

7. References

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FIGURE CAPTIONS

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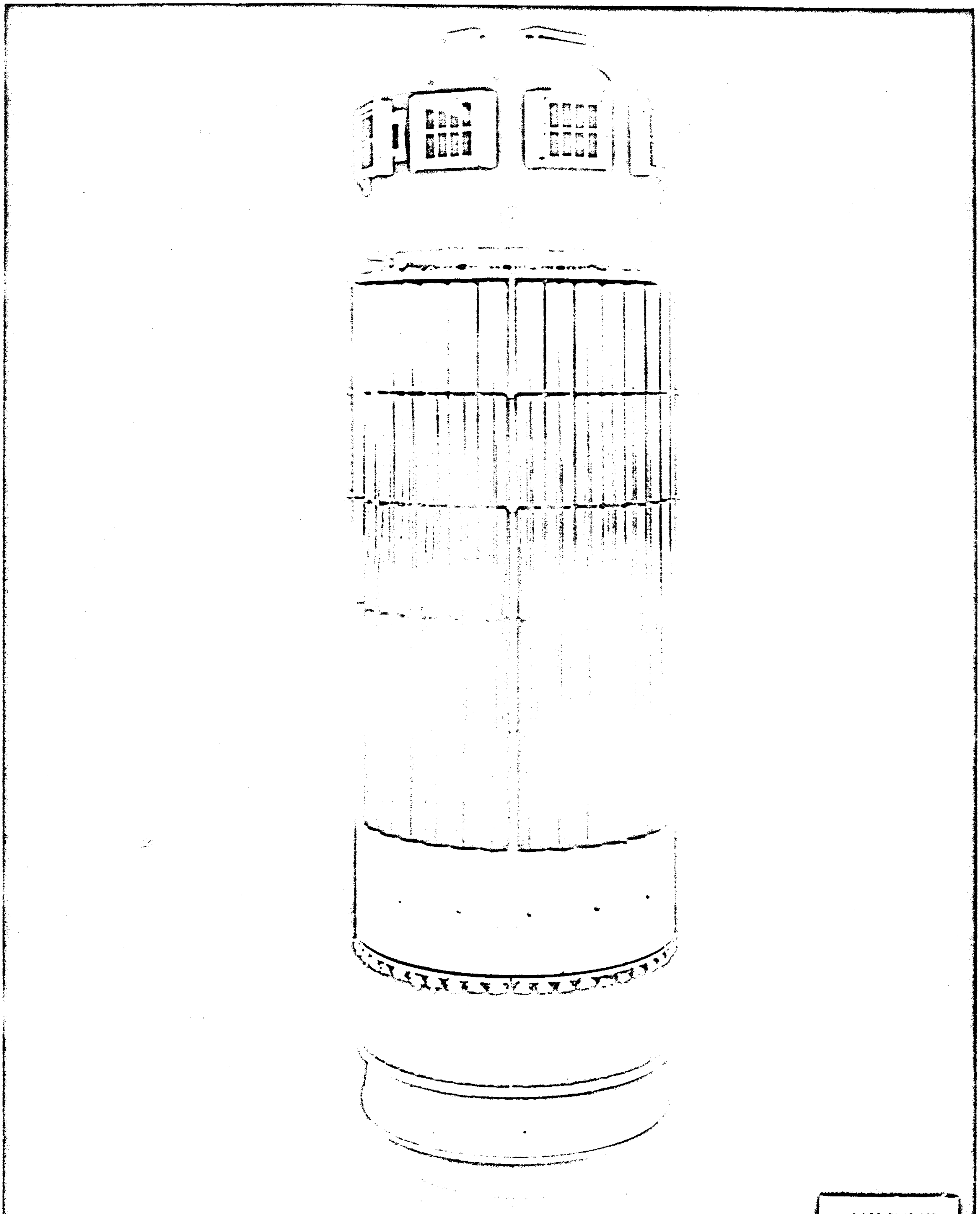

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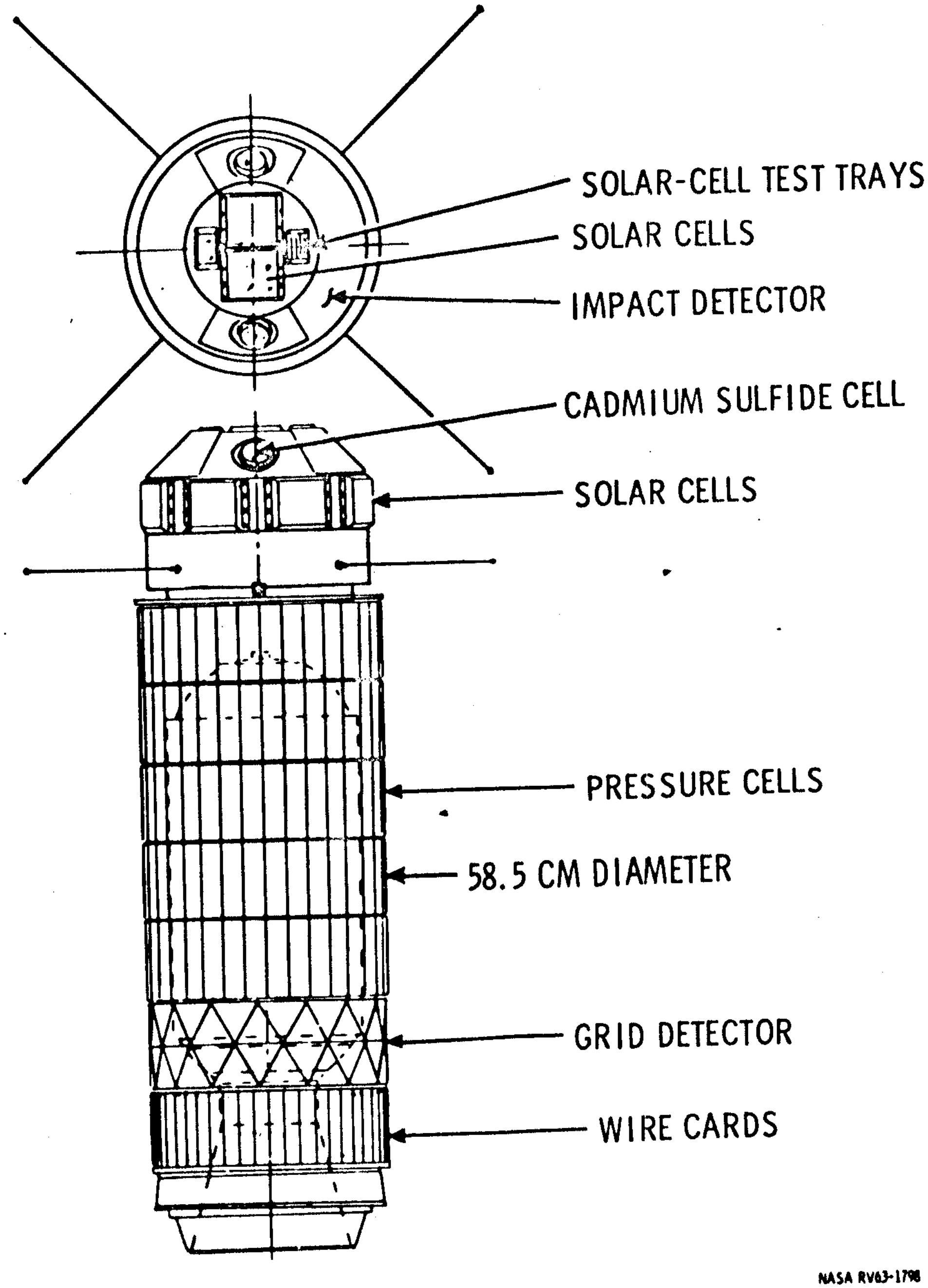
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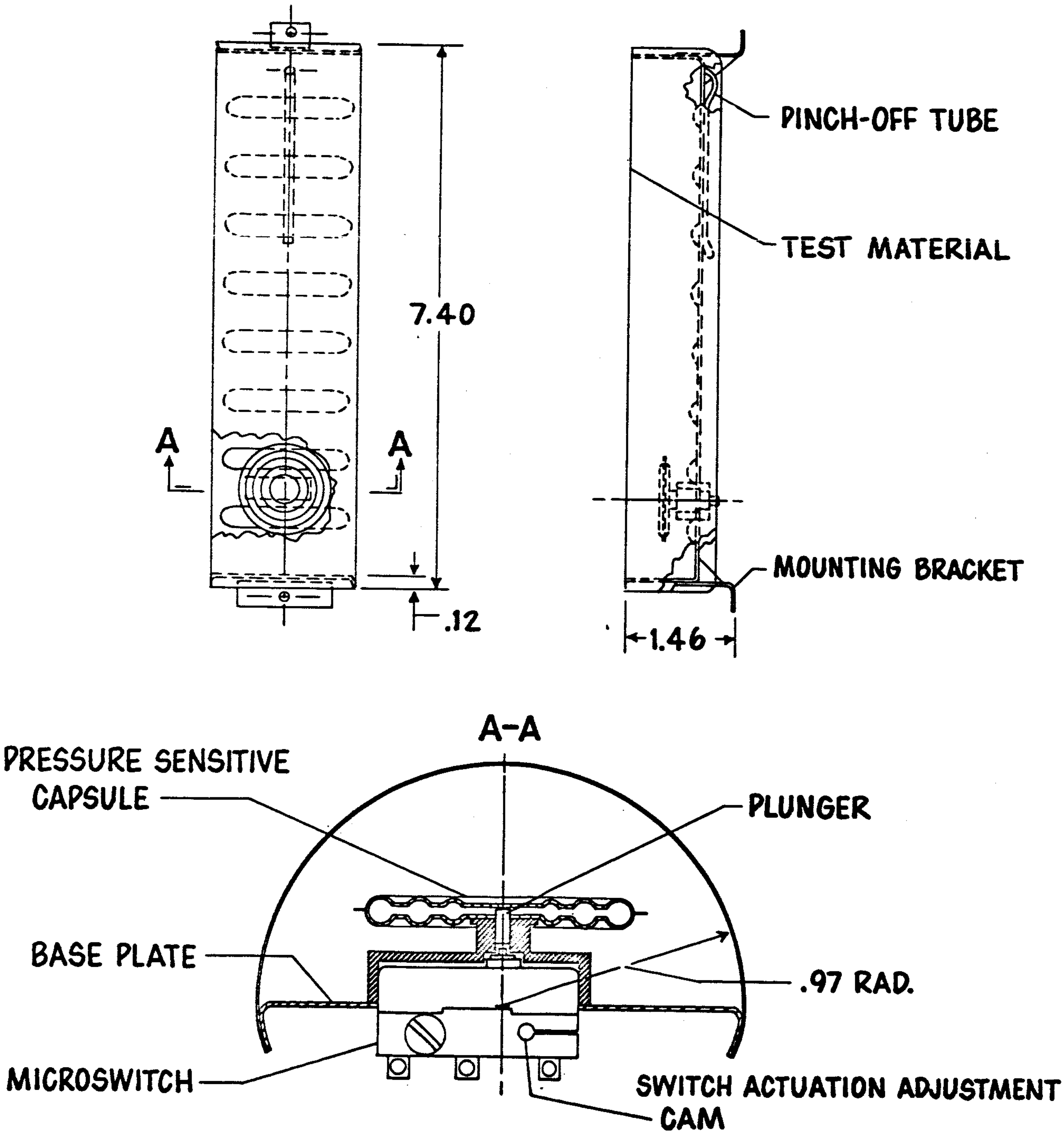

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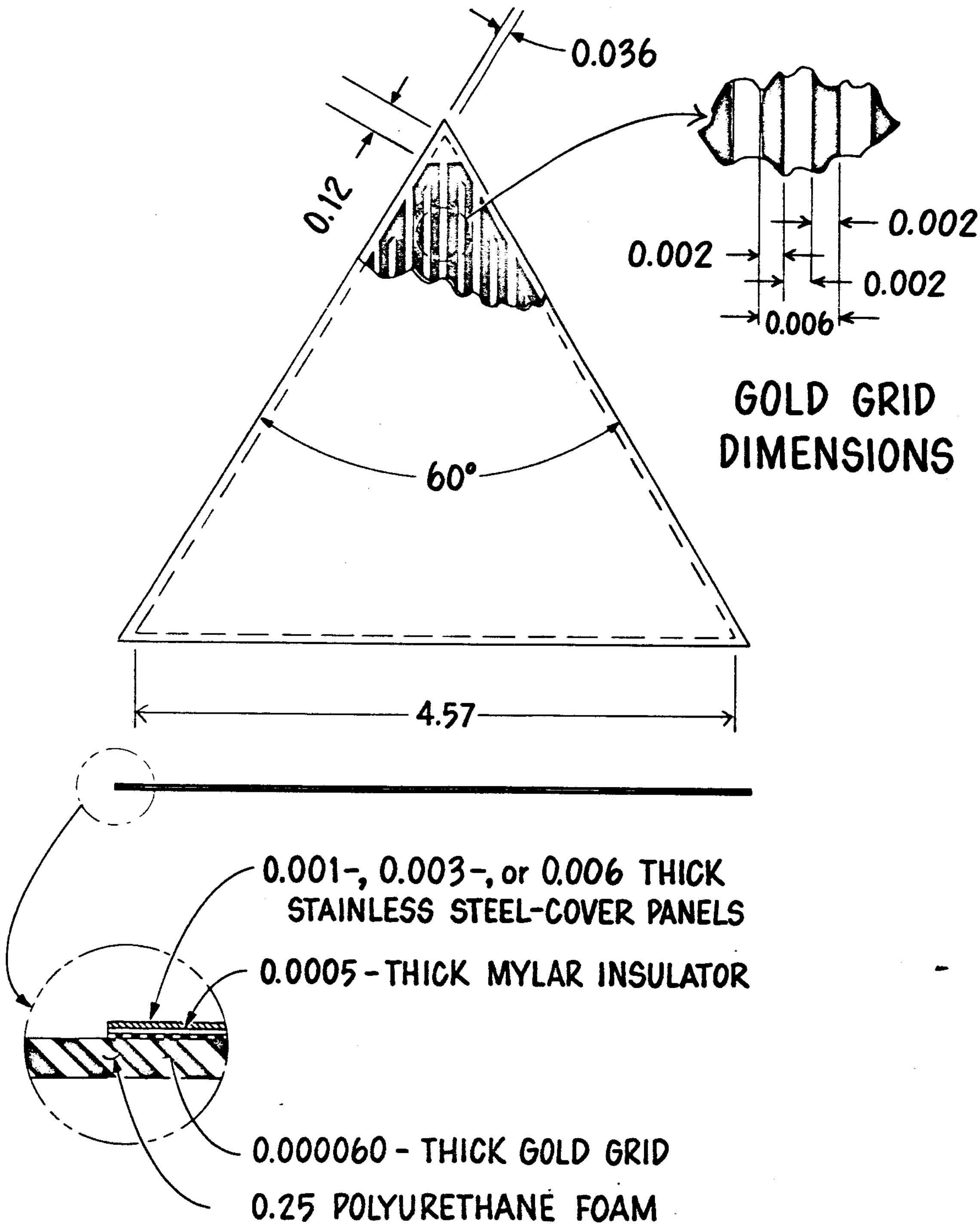

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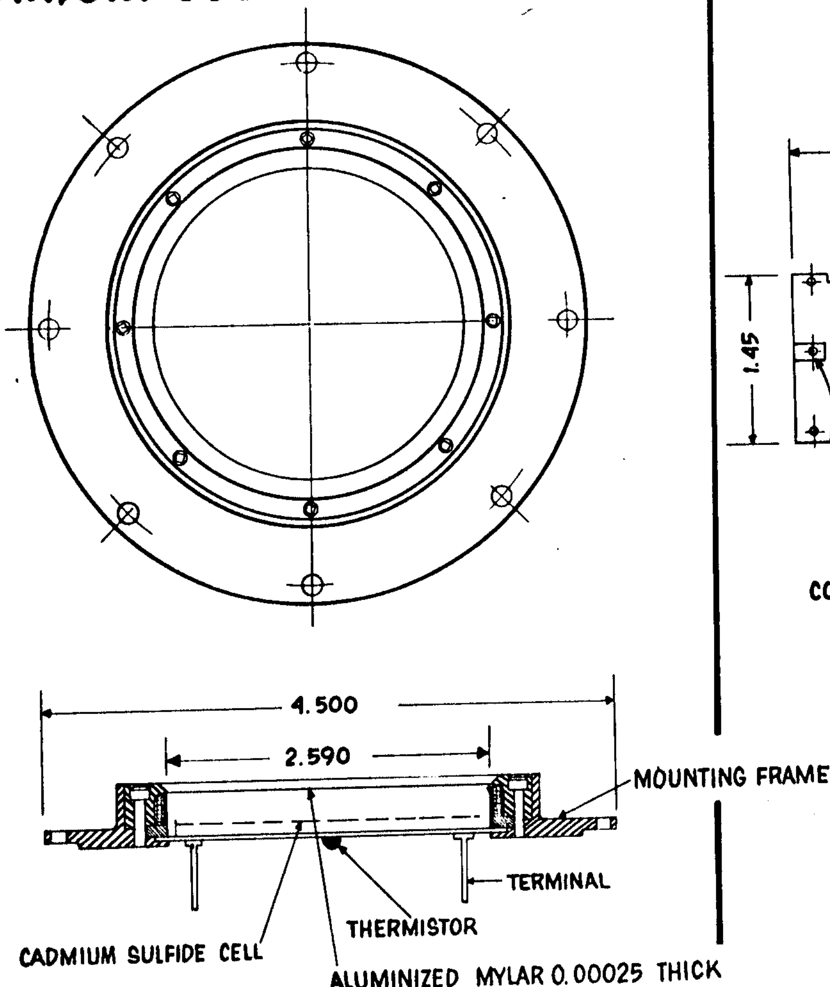

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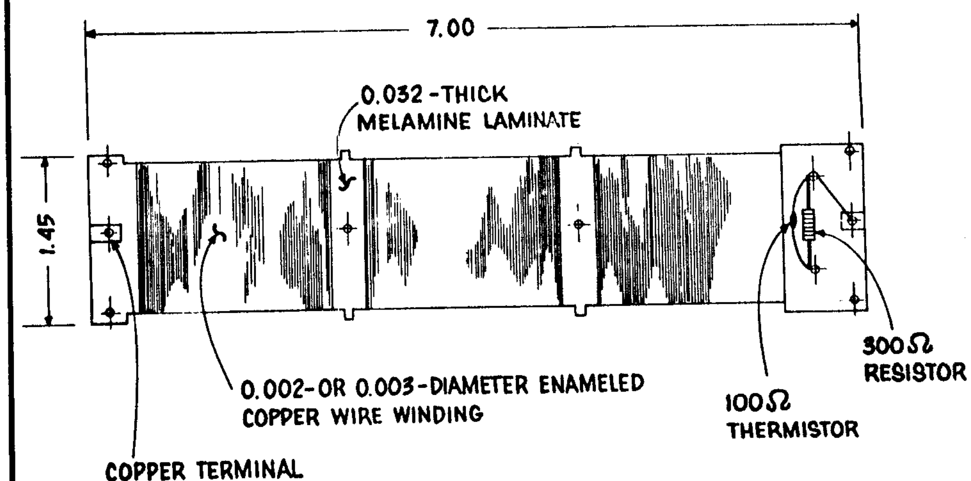

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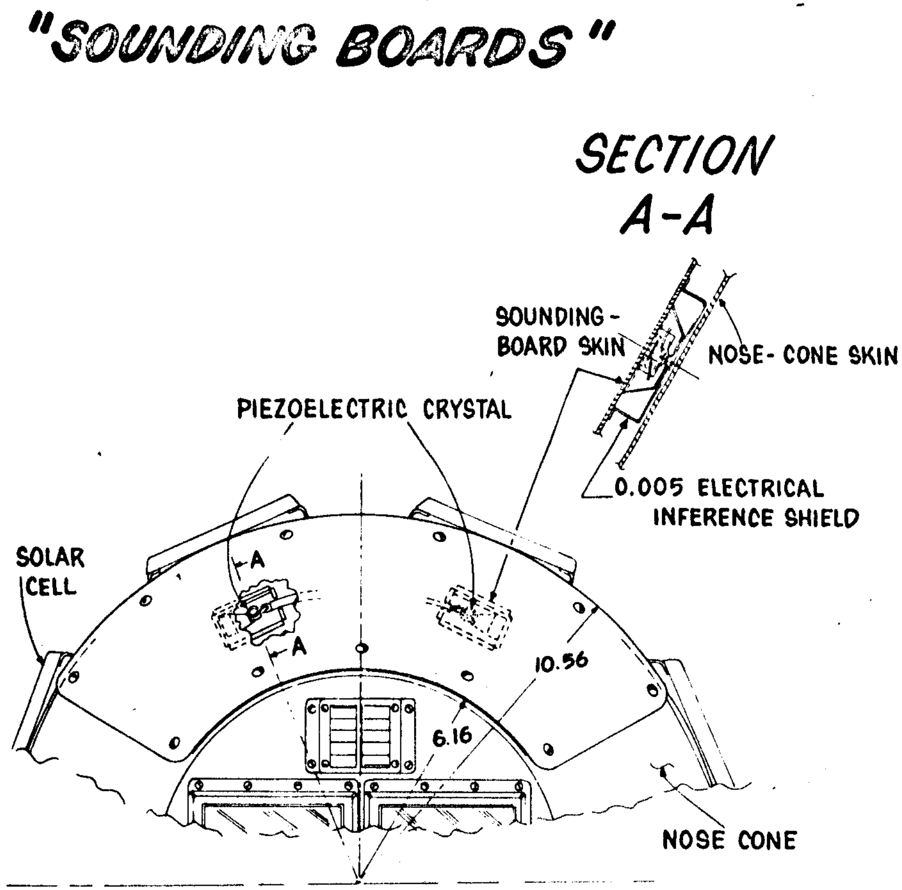

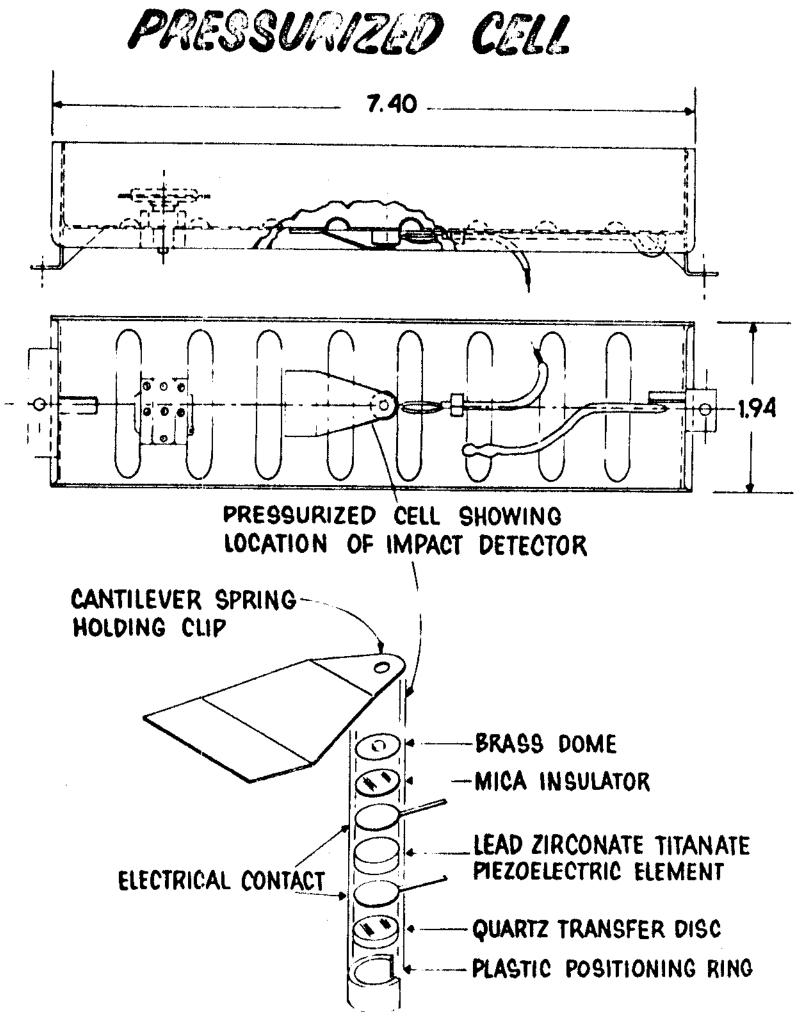

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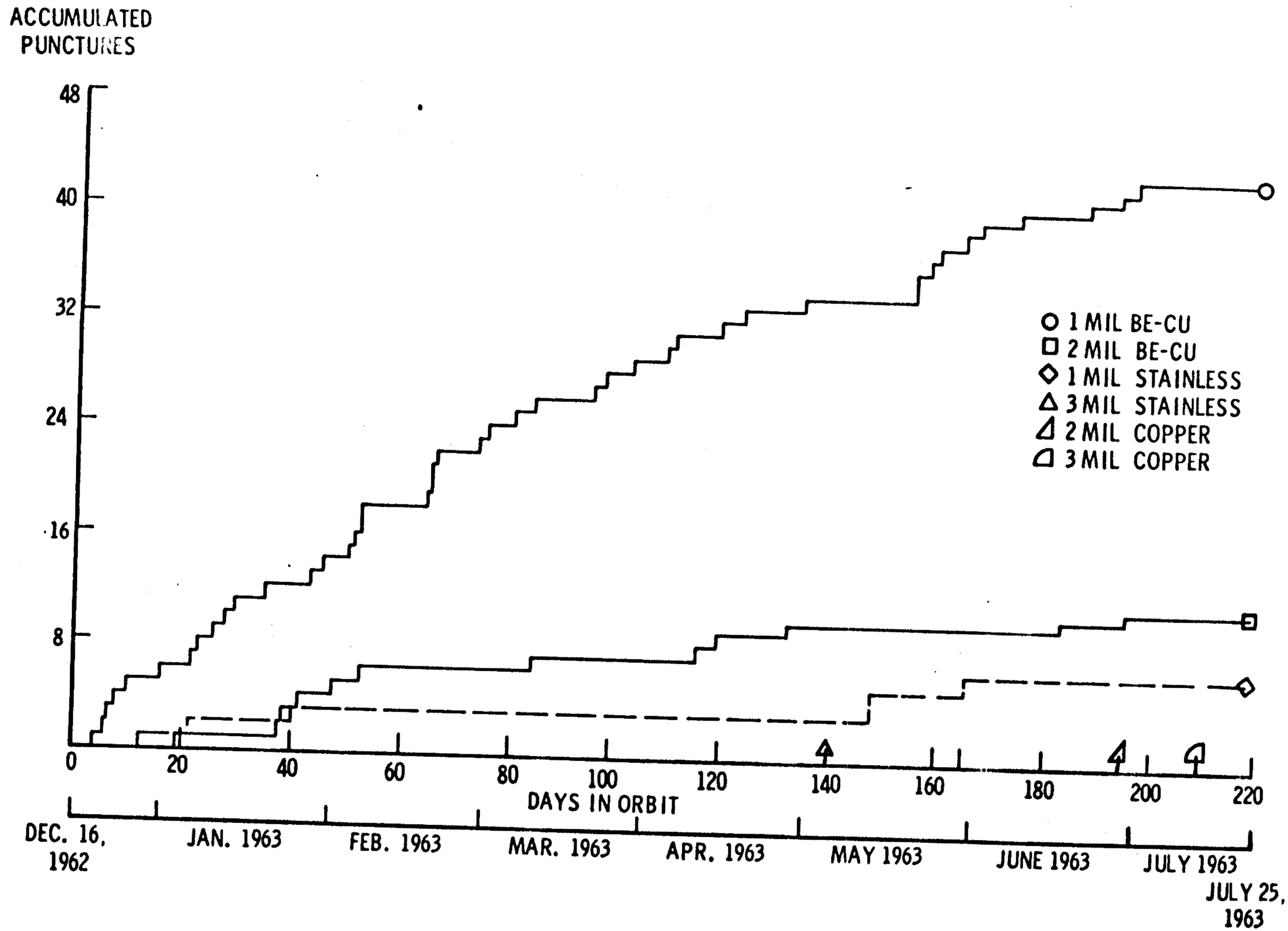
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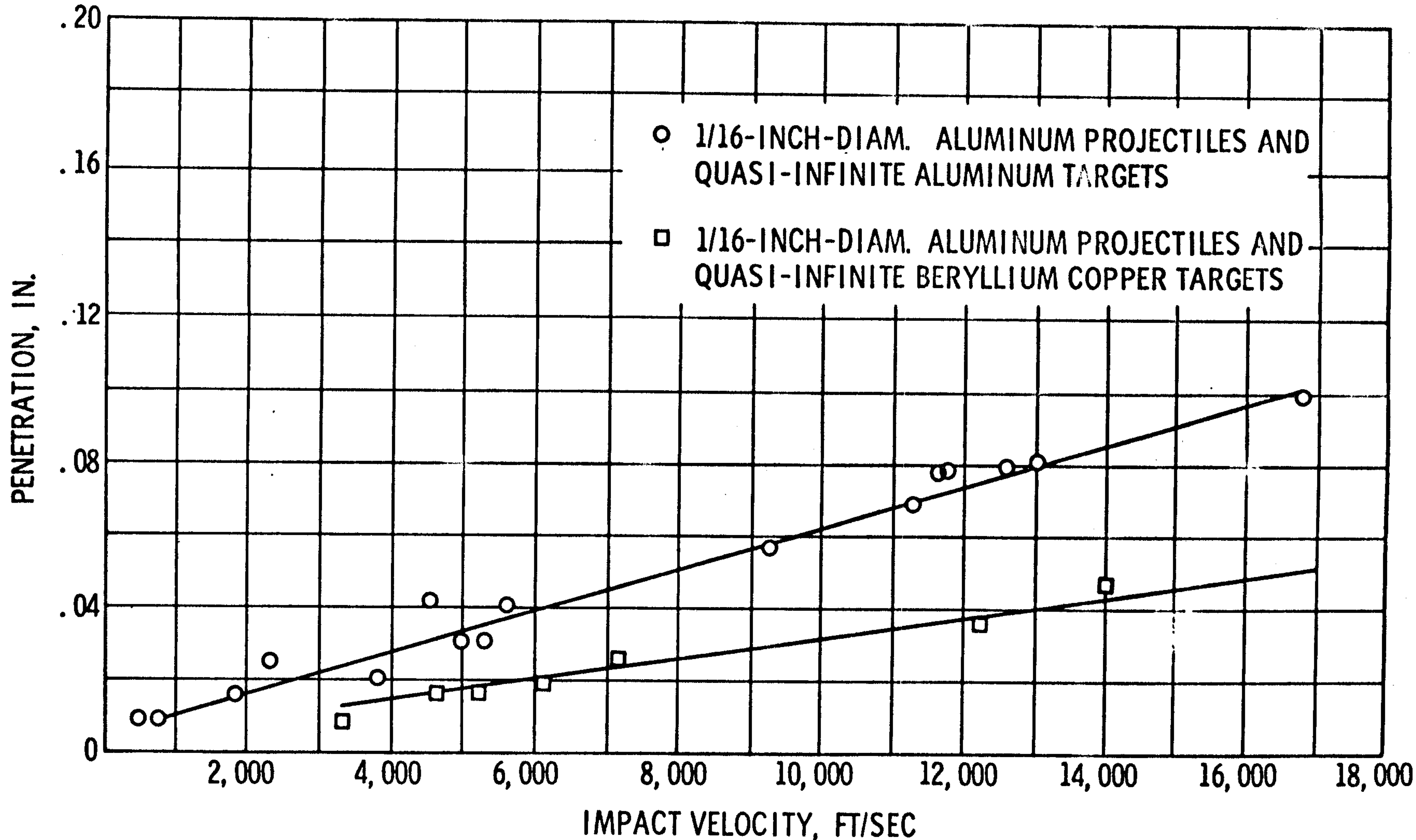

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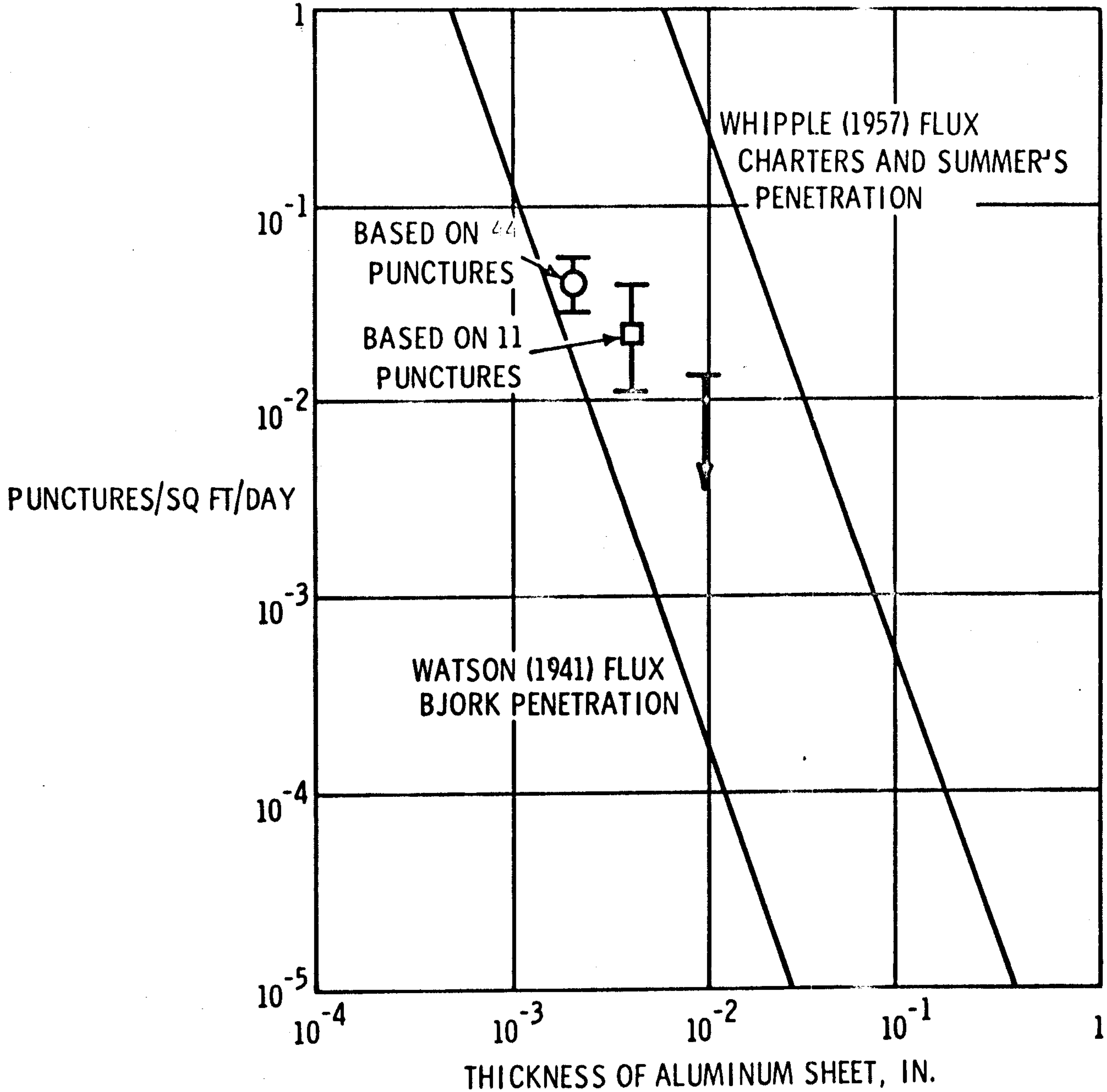

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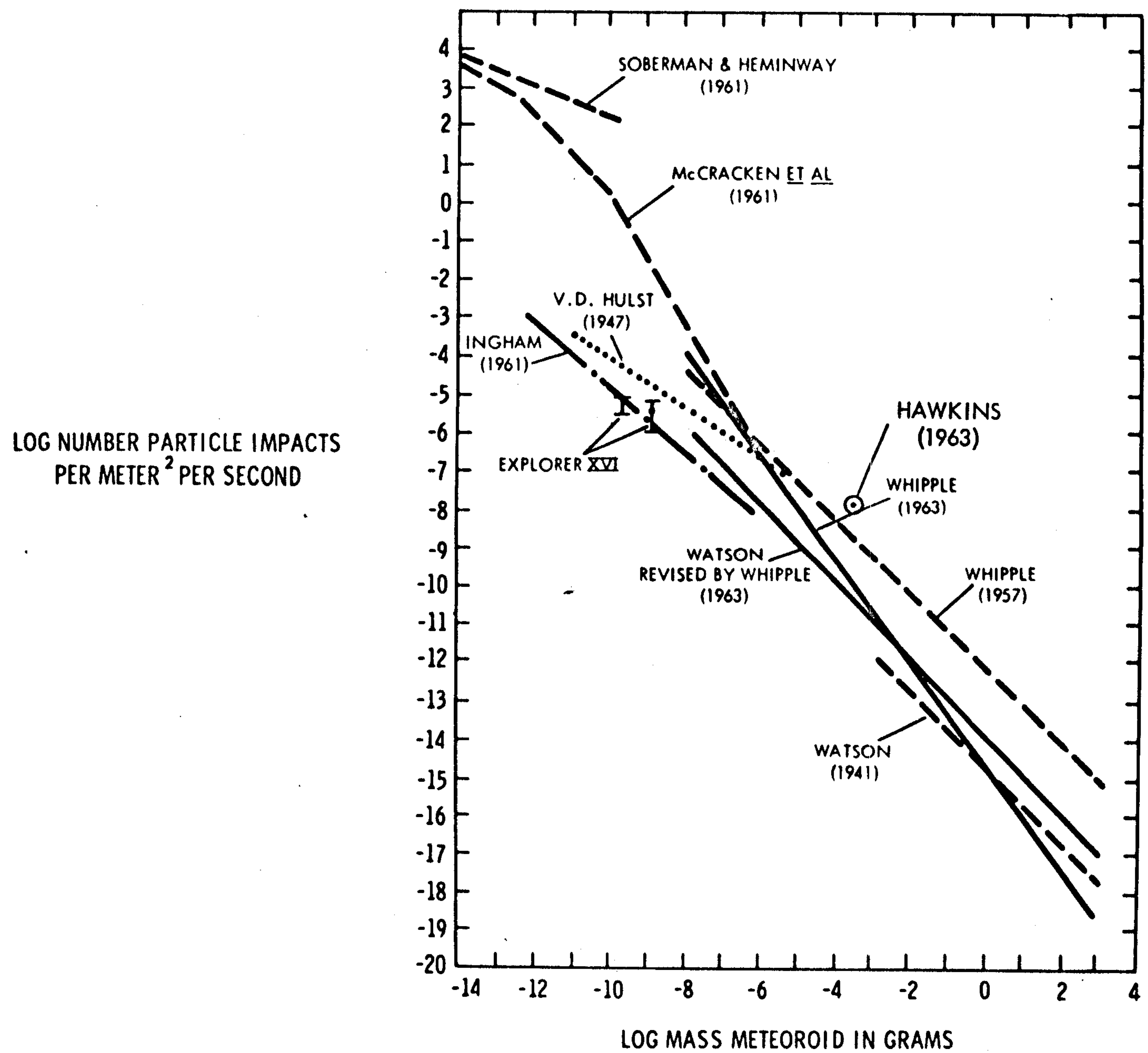

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